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(19)



(54) LOAD SHEDDING SYSTEMS

- (71) We, LOCKHEED ELECTRONICS CO. INC., a corporation of the State of California, with an office at U.S. Highway 22, Plainfield, New Jersey, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us and the method by which it is to be performed, to be particularly described in and by the following statement:
- This invention relates to stored program controlled apparatus for selectively shedding power consuming loads to maintain energy consumed during each monitoring interval within prescribed limits.
- The cost of electrical energy is an important economic expense factor in many industrial installations and applications - a matter reinforced by the marked fuel charge increase of recent years passed on by electrical utilities to their consumers. The cost of A.C. electrical energy paid by industry is dependent, as a generality, upon both energy (e.g. measured in kilowatt hours) consumed over a billing period (e.g., a month), and also the peak power consumption rate (e.g., the greatest number of kilowatt hours consumed during any 15 minute or half-hour period, or the like). The specific billing practices of utilities differ but all to the same effect of penalizing a power consumer who has a high peak power consumption rate vis-a-vis total power consumed. This charging practice, of course, assures an adequate return for power companies which must install capital generating equipment to satisfy peak rather than average demand.
- Thus, an industrial consumer which consumes electrical power at a high rate, even for a very short period of time, will be subject to a severe increase in its total power costs - in some areas applied as a higher rate for energy consumed by the user.
- In accordance with the invention there is provided a load shedding system for controlling the power supplied to a plurality of loads each selectively connectable to a source of energy, comprising stored program controlled digital computer means including a central processing means and memory means communicating with said central processing means, said memory means including data storage means for each load for storing the characteristics and status associated with the load and to be used in determining whether the load should be shed, a plurality of controllable switch means for selectively connecting and disconnecting the loads to and from the energy source, control circuitry responsive to signals issued by said computer means for controlling said controllable switch means, and means for signalling to said computer means the power being consumed by the loads, said computer means including means for projecting the energy consumption of the loads over a measuring interval, excessive power signalling means for comparing said projected energy consumption with a permissible limit therefore and for signalling when the projected consumption exceeds said permissible limit, and load shedding means responsive to said excessive power signalling means indicating an excessive projected energy consumption for examining said data storage means for selectively operating said controllable switch means via said control circuitry to operatively disconnect selected loads from the energy source.
- In a preferred embodiment of the invention, the characteristics (and use priority) of each load can be redefined as desired, in dependence on the passage of time, or an external sensor (e.g. for temperature, process rate or the like), or local or distant manual entry of information, as via a teletypewriter. Such parameters can be used to define an operational level for the loads, and this level can then be used to determine the values of the priorities and other characteristics of the

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loads.

Also, in the preferred embodiment, the system is expandable to accommodate further loads, and the loads and load controllers can be physically disposed at local and remote locations.

The specific embodiment of a load shedding system described below includes power consumption metering and meter interfacing circuitry for entering overall power consumption into a central processing unit. The CPU memory includes a data storage means for characterizing each system electrical load under each of a hierarchy of operational levels, and circuitry is provided for the CPU to turn local and remote loads on and off in accordance with stored energy consumption projecting and load shedding algorithms.

In brief, the digital computing apparatus operates on the meter supplied information and projects energy consumption over each of successive monitoring intervals. If power must be shed to obviate an excessive projected demand, loads are examined seriatim and selectively shed on a monotonically increasing priority basis as required, depending upon the operational parameters and status of each load for the then prevailing operational level condition.

An arrangement embodying the invention will now be described by way of example, with reference to the accompanying drawings, in which:

Figures 1A and 1B are respectively the left and right portions of a load shedding system in accordance with the present invention;

Figure 2 is a flow chart illustrating data processing to project power consumption over a monitoring interval, and for defining load shedding requirements; and

Figure 3 is a flow chart characterizing a data processing SHED algorithm selectively disabling loads as required.

Referring now to Figures 1A and 1B hereinafter referred to as composite Figure 1, there is shown a power monitoring and load shedding system embodying the principals of the present invention, which includes a power meter 10 for monitoring the power consumed by an array of loads 66, energized by an A.C. power source 59 via a power distribution bus 62. The power meter 10 supplies as a first output on a lead 12 information indicative of the rate energy is being consumed by the loads 66, typically in the form of a sequence of pulses where each pulse represents a predetermined quantum of energy. The power meter 10 will also typically supply at an output lead 14 synchronizing information identifying the relatively short period over which the energy consumed is to be determined. Thus, for example, where energy consumption is

monitored on the basis of fifteen minute intervals, the sync line 14 will be activated once every fifteen minutes. Alternatively, the monitoring periods may correspond to real time intervals (e.g., every quarter hour) and are signalled by a real time clock 41 discussed below.

It will be recalled that the charge for industrial power has a factor dependant upon the peak power consumed during any monitored interval. Accordingly, as an overall desideratum, the system operates to avoid excessive peak energy consumption during any monitoring interval signalled by the sync output of the meter 10. This is effected as a generality by changing the on/off status of lower priority loads to shift a portion of the energy requirements for such loads to periods when A.C. loads of a higher order of significance exhibit lower demand requirements.

To this end, demand meter interface circuitry 20 receives the power and synchronizing output information on leads 12 and 14 respectively from the power meter 10, and passes this data to a digital computer 30. As shown, the computer 30 employs a central processing unit 31 and a memory 32 for receiving and operating upon the power consumption information via a peripheral interface adapter (P.I.A.) 33 and common data and address busses 43 and 44. The particular structure shown for the digital computer 30 in Figure 1 (which includes a series of priority interrupt inputs 35 passing to a priority interrupt encoder 34) is merely illustrative and may be implemented by a range of processor equipments including standard general purpose computers, mini-computers and micro-processors. For example, the mini-computer vended by us under the trade style MAC 16 may be utilized.

In accordance with conventional common data and address bus 43 and 44 computer operation, the demand meter interface circuitry 20 (as well as contact and control circuitry 48, status circuitry 70, sensor(s) 42, and a remote coupler 73, all discussed below) are treated as peripherals connected to the system busses 43 and 44 for selection and connection - for unilateral or bilateral information transmission as required, with the computer 30 and CPU 31 in particular.

To this end, the demand meter interface circuitry 20 includes a counter 22 advanced by the energy consumption signalling pulses supplied by the meter 10, and a status register 24 (e.g., a simple flip-flop) which is set when each new sync pulse is received from the meter 10 via the lead 14. The outputs from the counter 22 and status register 24 are selectively gated by gate circuitry 26 onto the data bus when the interface circuitry 20 is addressed by the computer 30 via the address bus 44. Again as is conventional for

common bus computer cooperation for "peripheral" selection, the interface circuitry 20 includes an address decoder 27 connected to the address bus 44 to determine whether the circuitry 20 is being polled by the CPU 31 and, if so, to enable the gate 26 to multiplex the counter 22 and status register 24 contents onto the data bus 43 for communication to the CPU 31. A delay element 28 operates to clear the status register 24 (e.g. reset a status flip-flop) at the conclusion of each polling cycle. In this manner, a computer variable, ascribed the mnemonic name "PCTR", identifying the count state of the counter 22, is loaded into an appropriate storage cell (schematically denominated PCTR) via the central processing unit 31.

Contact and control circuitry 48 is employed to actuate/disable the power consuming loads 66. There may, and generally will be power-draining loads connected to the power source 59 which may not be switched on or off by the CPU 31. The power consumed by such loads is, of course, reflected in the output of power meter 10 and thus taken into account by the instant apparatus. However, beyond this observation such loads are not further considered.

The contact and control circuit 48 includes a control register 49 loaded via the data bus 43 when the circuitry 48 is identified by the contents of the address bus 44. As again is conventional in the common bus digital computer field, each of the circuits communicating with the CPU 31 via the common busses 43 and 44, e.g., the circuitry 20, 42, 48, 70 and 73 herein discussed, includes an address decoder comparable to the decoder 27 shown in the meter interface circuitry 20 specifically discussed above (each decoder, of course, being adapted to respond to a unique digital address word). Each address decoder responds to computer 30 generated address signals on the address bus 44 which identify when that "peripheral" unit is selected by the computer 30 for communications therewith and appropriately connects the selected peripheral unit to the data bus (as via gate 26 shown for the interface circuitry 20). The apparatus comparable to the address decoder 27 and multiplexing element 26 discussed in conjunction with the meter interface circuitry 20 will hereinbelow be presumed to be included in all apparatus connected to the common data and address busses 43 and 44 (and to any remote data and address busses 43' and 44') and will not be further considered.

Returning now to the specific operation of the contact and control circuitry 48, the i-th stage of the register 49 is selectively energizes/de-energizes the coil 50_i of an associated relay 52_i for selectively controlling the energized/de-energized state of a

corresponding load 66_i. The load 66_i is selectively connected to the source of A.C. power 59 via a power contact 65_i of a relay 60_i having a relay activating coil 61_i. The relay coil 61_i is selectively connected by one transfer switch member 54_i of a two pole, three position switch 53_i and a normally open contact 51_i of the relay 52_i.

To illustrate load control by way of a specific example, and with the double pole switch 53_i in its uppermost position as in the drawing, when the i-th stage of the register 49 signals that the load 66_i is to be energized, its presents an appropriate binary digit, e.g., a binary "1". This output bit energizes the coil 50_i, either directly for a sensitive relay or indirectly via a buffer amplifier or gate (not shown) thus actuating the relay contacts 51_i. The closed contacts 51_i complete an energizing circuit path for the relay 60_i, located at the load 66_i location, via normally closed contacts 63_i (discussed below). The energized relay 60_i closes normally open contacts 65_i, thus completing the circuit from the A.C. power source 59 to the load 66_i.

Correspondingly, if a "power off" bit (e.g., a "0") is present at the i-th stage of register 49, the relays 60_i and 52_i are not energized, and the load 66_i is disconnected from the power source 59 via opened contact 65_i.

The normally closed contacts 63_i may be disposed in the load area to disable a relay 60_i (and thereby also the load 66_i) independent of the output of the processor 31 as loaded into the register 49. Thus, for example, the contacts 63_i may comprise an emergency switch, and could be operated by the output of a local sensor responsive to signal overload or excessive temperature conditions, or the like.

The second pole 55_i of each switch 53_i in the contact and control circuitry 48 is coupled as an input by a conductor 56_i to a respective stage of a register 71 in status circuitry 70, as is a signal passing through a second contact 64_i of the load controlling relay 60_i via a conductor 67_i. The signal conveyed to the register 71 by the conductor 56_i reports to the CPU 31 whether or not the load 66_i is capable of being controlled by the computer 30, i.e., energized or shed as required. To this end, note that if the double pole switch 53_i is in other than its uppermost position, the load 66_i cannot be controlled by the CPU 31 which no longer has access to the relay 60_i. This fact is reported to register 71 by the switch transfer member 55_i which supplies a ground signal (a binary "0" in one commonplace logic convention) when switch 53_i is in its uppermost position, and an open circuit signal (a "1") otherwise.

Similarly, the ground/open circuit signal reported to the register 71 via contact 64_i and lead 67_i confirm to the CPU 31 the

actual state of a controlled load 66, independent of the command issued therefor by the computer 30. To this end, note that the computer 30 may signal that load 66 be energized when, in fact, the load may be unenergized, as by an opening of the contacts 63; because of some locally prevailing condition at the load 66, because of a system fault in circuitry 48, a severed conductor, or the like.

Accordingly, the above described system apparatus is fully effective to load power consumption and synchronizing information from the meter 10 into the CPU 31 and memory 32, to issue commands from the memory 32 and CPU 31 to turn each controlled load 66 on or off, and to monitor the status thereof via the status circuitry 70.

By way of additional system apparatus, the computer 30 includes a priority interrupt encoder 34 to directly input into the central processing unit 31 on a priority basis a signal from circuitry 36 signalling that power has failed; messages supplied by external peripheral units 38, e.g., a teletypewriter; and time of day information supplied by a real time clock 41. Again, as well known to those skilled in the art, the informational sources 36, 38, 41 may alternatively be connected as additional "peripherals" to the busses 43 and 44 rather than supply information via the CPU interrupt encoder 34 (and the "peripheral" units could be connected via the priority interrupt encoder with or without direct memory access). Also, where a mini-computer is employed with priority interrupt capability (such as the aforementioned LEC 16 assemblage), no separate priority interrupt encoder 34 need be employed.

The Figure 1 system further includes sensors 42, e.g., each connected as a peripheral to the data and address busses 43 and 44 to supply thereto signals characterizing those parameters of the controlled industrial plant which are of interest in making power shedding decisions. For example, such parameters may comprise ambient temperature (which may, for example, establish priorities for heating/cooling A.C. loads), plant process rate, product mix, or the like.

In accordance with one aspect of the present invention, the above considered apparatus may be employed as well to control loads disposed in locations spatially remote from the CPU 31, e.g. loads 66' and 66". To this end, signal coupling apparatus connects the busses 43 and 44 with a remote system controller 82 which, in turn, operates remote data and address busses 43' and 44' in a manner comparable to the busses 43 and 44 directly controlled by the computer 30. Connected to the busses 43' and 44' are demand meter interface circuitry 20' connected to a load 66' monitoring power meter

10' (the A.C. source and relays comparable to relays 60' being deleted for clarity), contact and control circuitry 48' and status circuitry 70' which perform in a manner directly analogous to the like unprime-numbered elements discussed above. Thus, for example, a remote coupler 73 including a UART 74 (universal asynchronous receiver and transmitter), versions of which are available from several different manufacturers in integrated circuit form, may be employed to communicate with a UART 84 in the remote system controller 82. For communication over an extended distance, modems 79 and 80 are employed, with data signalling being effected over a duplex circuit 76, 78. Where long distance communications are not required, the output of the UART 74 may be directly connected to a remote system control 82 for controlling power loads.

Remote system controller 82 may include an address decoder 87 for identifying that it is the peripheral unit being addressed by the computer 30 and for enabling a command decoder 89 to enable a sequencer 90, e.g., a counter-encoder combination, to actuate the interface circuitry 20', the circuitry 48' and the circuitry 70' in turn via the remote address bus 44', communication with the CPU 31 being achieved via the remote data bus 43', a data register 86, and the UART 84-TO-UART 74 communications link.

Yet further loads 66" may be controlled via a remote multiplexer peripheral unit 102 connected to any of the system data, address busses 43, 44, or 43', 44', whichever is more physically convenient to the loads 66". The remote multiplexer 102 operates to supply A.C. power from a power source 106 to loads 66" as well as control information. To this end, multiplexer 102 includes an encoder 104 to encode the bus 43', 44' information in a manner suitable for multiplexing with 60 cycle A.C. power from source 106, which may be delivered on a twisted pair 111. Such power/signal multiplexing may be effected in varying ways well known to those skilled in the art, e.g., by utilizing frequency division multiplexing as where the encoder performs frequency shift keying, amplitude or frequency modulation, PCM, PAM, or the like.

At the load location, a powerless terminal 110 includes a separation filter 112 for delivering the low frequency A.C. power to latch and relay circuitry 118, and for supplying the control information to a decoder 115. The decoder 115 enters data in the latch (register) portion of circuitry 118 which effects a control function to deliver the A.C. power to those of the array of controlled loads 66" which are to be turned on in accordance with the information last supplied by the decoder 115.

Thus, the composite Figure 1 apparatus

includes all requisite apparatus for monitoring and controlling loads 66, 66' and 66" in local and remote locations - even in remote locations in which A.C. energy is not locally available.

The particular manner in which the Figure 1 apparatus, and the central processing unit 31 and memory 32 in particular, operate to control the loads 66, shedding power consuming devices as required, will now be considered. In the illustrative discussion below, non-literal FORTRAN-type coding statements will be presented to characterize data processing. It will, of course, be readily apparent to those skilled in the art that any other program language may be employed to effect the basic computational algorithms described.

Referring now to Figure 2, there is shown a flow chart for data processing by the central processing unit 31 and memory 32 to project energy consumption over the monitoring interval, e.g., each assumed 15 minute period. It will be recalled from Figure 1 that the synchronizing output signal conductor 14 from the power meter 10 will typically supply the requisite synchronizing information. Alternatively, where absolute real time periods, e.g., every quarter hour, are utilized to compute peak demand, such monitoring periods are derived from the information supplied to the computer by the real time clock 41 rather than the meter 10.

For the computation depicted in Figure 2, let computational variables (as well known to those skilled in the art, each corresponding to a storage location in memory 32) be defined as follows:

ACT = Total energy consumed from the inception of a monitoring period;

ENLIM = The maximum energy permitted to be consumed over the monitoring interval;

ENSV = Minimum energy shedding requirement if the equipment is operating in an energy saving mode;

MTG = Minutes to go in the energy consumption metering cycle, e.g., initialized at 15 for a 15 minute monitoring period and decremented by one for each one minute passage of time as reported by the real time clock 41;

PCTR = The last count state of counter 22, which is periodically supplied to the CPU as the demand meter interface circuitry 20 is polled by the computer 30, e.g., once each minute;

PCTR1 = The state of counter 22 during the last previous counter 22 polling operation (i.e. the previous value of PCTR);

PRES = Energy consumed over the last polling period, i.e., over one minute for the assumed case;

PRES1

PRES2 = Energy consumed during the

one minute and two minute previous periods, respectively;

PROJ = Energy consumption projected over the full monitoring period interval and

PRTE = Present overall rate of power consumption.

To illustrate operation of the Figure 2 power consumption projecting algorithm, which iteratively repeats during the assumed fifteen minute monitoring period, examine now data processing beginning an iteration during the intermediate part of the period. As a first matter, the state of the counter 22 is read into the PCTR variable location in memory 32 (step 150) by any conventional data entry statement. The power consumed during the previous one minute period (PRES) may then be determined by

$$PRES = (PCTR - PCTR1) * K \quad (1)$$

where (PCTR - PCTR1) is the incremental count accumulated over the last one minute polling period, and K is a count-to-energy consumption conversion factor (step 152).

The present rate at which energy is being consumed (PRTE) - i.e., average power over the last one minute, is then

$$PRTE = (PRES * 2 + PRES1 + PRES2) / 4 \quad (2)$$

determined as the weighted average of power consumed during the last interval (PRES being given double significance) and over the previous two one minute periods as stored in PRES1 and PRES2 (step 153).

The actual power consumed from the beginning of the monitoring period through the present time (ACT) is updated,

$$ACT = ACT + PRES. \quad (3)$$

The total energy projected to be consumed over the entire monitoring period (15 minutes) PROJ is computed by adding the actual power consumed from the beginning of the period to the present (ACT) to the power predicted to be consumed over the remaining interval (product of the rate at which power is being consumed (PRTE) and the time remaining in the period (MTG)), as by

$$PROJ = ACT + PRTE * MTG \quad (4)$$

(steps 155 and 159).

Thus following the functional computation 159 the CPU 31 has available to it a projection of the energy which will be consumed over the monitoring interval (stored in PROJ). Before testing the contents of PROJ against the permissible energy limits (e.g., stored in ENLIM), the computational variables MTG, PRES2, PRES1, and PCTR1 are updated to be in a proper state for the next computational cycle (step 160). The statements

$$MTG = MTG - 1 \quad (5)$$

$$PRES1 = PRES \quad (6)$$

$$PRES2 = PRES1 \quad (7)$$

$$PCTR1 = PCTR \quad (8)$$

may be employed.

To determine whether some present system A.C. load(s) 66 need be shed, the projected energy consumed during the period (PRØJ) is compared with the maximum permissible consumption (ENLIM) in any program language testing and conditional branching routine well known *per se* (functional block 161). If the contents of PRØJ exceeded those of ENLIM, indicating that power must be shed (a "yes" result from the program test 161), a variable SHEDRQ containing the requirement of power to be shed is set to the difference,

$$\text{SHEDRQ} = \text{PRØJ} - \text{ENLIM} + \text{SHEDRQ} \quad (9)$$

If the equipment is operating in an energy saving mode where a minimum amount of energy (stored in ENSV) is to be shed independent of any actual excessive power rate, SHEDRQ is initialized to ENSV, e.g., at the beginning of each monitoring period, before entry into Fig. 2 processing.

Thus, by way of summary, the Figure 2 algorithm constantly projects the total energy which will be consumed over the monitoring period (contents of PRØJ) by measuring the power actually consumed from the beginning of the monitoring period to present, and projecting future consumption based upon a weighted average of the rate of consumption. The projected consumption PRØJ is then tested against the maximum permissible consumption (contents of ENLIM) and, if power is being consumed at an excessive rate, defines in a variable cell SHEDRQ the amount of power which must be eliminated to bring consumption down to a point where ENLIM is not exceeded (or to eliminate the ENSV amount if a power saver mode is employed).

Referring now to Figure 3 there is shown the SHED algorithm which operates once SHEDRQ has been defined to actually turn off the necessary loads 66 to satisfy the power reduction requirement of SHEDRQ.

For purposes of the Figure 3 algorithm, let additional storage variables be defined as follows:

M = an indexing variable identifying consecutive ones of the loads 66;

I = the operational level for each of the m loads (more fully discussed below);

J = the priority level at which loads 66 are being shed, e.g., with J beginning at zero and with increasing numbers representing increasing priorities;

PRTY (M,I) = is a two dimensional variable signalling the priority entry in a load M data table for level I;

STATUS (M) = a one dimensional variable indicating the entry in the load M data table signalling whether the load is on or off, the binary bits "1" and "0" being assumed to respectively signal on and off conditions;

TIME = is a variable representing time of

day reported by the real time clock 41

TRATM(M) = a storage cell in the data table of a load M indicating the time of the last actuation or deactuation of the load (e.g., when it was last either turned on or turned off);

TIMØN(M) = a variable signalling when the load M is to again be turned on;

ØFTM(M,I) = the minimum off time for a particular load M when operated at level I;

ØNTM(M,I) = the minimum on time for a particular load M when operated at level I;

LOAD (M) = is a load M data entry indicating the power saved when the load is off rather than on; and

DNG = is a danger priority level.

As anticipated by the process variable designation table above, there is associated with each load 66, a data table which includes level-independent variables (associated with respective storage locations) which indicate whether the device is off or on (STATUS (M)), the power consumed by the device when on - and power saved when off (LOAD(M)); the time the device was last turned on or off (TRATM(M)); and the time an off device is to be turned on (ØNTM(M)). There is also included in the data table for each load a plurality of storage cells (which may comprise portions of one or more memory 32 locations) the contents of which vary with the operational level defining variable (I) for all loads. Thus, for example, it may be desired to differently describe loads, e.g., as to priority (PRTY(M,I)) or minimum off or on time (ØFTM(M,I), ØNTM(M,I)) depending upon business hours vis-a-vis non-business week day hours vis-a-vis weekend or holiday times; to differently characterize loads depending upon some operational or environmental factor such as a temperature reported by sensor(s) 42; or to select load level via an input message entered via an input peripheral such as the teletypewriter 38. By way of one specific example, it will be apparent that an A.C. load such as air conditioning will be given a much higher load shedding priority when a sensor 42 is reporting an elevated temperature rather than a lower reported temperature. Similarly, priorities, minimum off and on times, and other level dependent variables will vary for lights, pumps, and the like depending upon such possible factors as required production time versus non-production time, cooling requirements, low material hopper fill levels, and the like.

As a conceptual matter, it is important to distinguish the level (I) which is used to establish the priority and some operational properties of each of the loads 66, from the J-priority variable, which defines the priority level at which loads are shed. As part of the Figure 3 algorithm, where some loads up

to the SHEDRQ requirement must be shed, the system first compares the lowest priority level ($J = 0$) with each load's priority at the then obtaining operational level, or I state (whatever that level is) and selectively shuts off some or all of the loads of priority zero, decrementing SHEDRQ as each load is shed.

If, after completion of processing for the lowest priority level ($J = 0$) insufficient loads have been shed, J is incremented to the next level ($J = 1$) and shedding continues until the contents of SHEDRQ are satisfied. Throughout this procedure, the operational level variable "I" will typically not change (unless there is a teletype message, sensor input or the like causing such change). Of course, if desired, it is possible to make I a function of J.

The SHED algorithm considered above will now be discussed in greater detail in conjunction with the flow chart of Figure 3. When the SHED routine is entered (as by defining a requirement to shed power in SHEDRQ), the load indexing variable M is initialized to 1 such that the processor 31 first considers the load 66, and the priority variable J is set to 0 to attempt to shed the amount of power defined by the contents of SHEDRQ at the lowest load priority (step 202), as by

$$\begin{aligned} J &= 0, & (10) \\ M &= 1 & (11) \end{aligned}$$

Obviously also, all other processing initialization is effected as well.

The CPU 31 and memory 32 next fetch the indexed (M) load data, i.e., the data characterizing the load 66, for the level I defined external to the SHED routine. The data block for the M-th load 66, comprises level-independent variables such as power ($L\phi AD(M)$), time of last transaction ($TRATM(M)$), on-off status ($STATUS(M)$); and level dependent variables such as priority ($PRTY(M,I)$) and minimum off and on times ($\phi FTM(M,I)$) and ($\phi NTM(M,I)$). If a CPU 31 with a plurality of storage registers is employed, all such load describing variables may be stored in the CPU 31, the CPU 31 thus including both the central processing means and the memory means. Alternatively, as is conventional for indirect addressing, an index register or the like may be utilized to extract the load M parameters as required. Other data storage arrangements are also well known to those skilled in the art for obtaining the load characteristics when needed.

After the load descriptors are obtained and/or isolated by step 205 (Fig. 3) functional blocks 207, 210 and 212 test the load descriptors to determine whether or not the load may be turned off. In particular, test 207 examines the level dependent load priority ($PRTY(M,I)$) to determine whether

or not the priority is less than the contents of J (J being at the lowest or 0 priority setting for the first iteration through the SHED loop). Assuming the test 207 is satisfied (acceptable load priority), test 210 examines the status ($STATUS(M)$) of the M-th load being tested to determine whether the load is on. It is obviously impossible to save energy by turning off a load which is already off. For a load which is on (test 210 satisfied), a test 212 determines that it has been on long enough, i.e., that the difference between the present time (TIME) and the time the device was turned off ($TRATM(M)$) exceeds the minimum on time for level I ($\phi NTM(M,I)$). If, and only if, each of the three tests 207, 210 and 212 are satisfied, the computer turns off the M-th load 66 (step 214). The load turn off is effected in the manner above described by the CPU 31 entering a "0" binary digit in the M-th stage storage of the register 49.

Following load turn off, functional block 215 up-dates information in the data block associated with the M-th load to reflect its new, "off" status. In particular, a time on one-dimensional variable cell $TIM\phi N(M)$, which establishes the real time when the load M is to again be turned on is set equal to the sum of the present time (TIME) and the minimum off period for the load M at the level I ($\phi FTM(I)$), i.e.,

$$TIM\phi N(M) = TIME + \phi FTM(M,I). \quad (12)$$

The status ($STATUS(M)$) of load M is set to 0 to reflect the fact that the load M is turned off, and the transaction time ($TRATM(M)$) variable for the load M is set equal to time ($TRATM(M) = TIME$) to indicate when the load M was turned off.

The SHED algorithm next computes the energy saved during the monitoring interval (ESV) by having the M-th load off. The energy saved (ESV) during the interval is the product of the power saved by turning the load off ($L\phi AD(M)$) and the lesser of the time remaining in the monitoring interval (MTG) and the time that the load will be off at the I-th operational level ($\phi FTM(M,I)$). Thus, a test 218 determine whether or not MTG exceeds $\phi FTM(M,I)$ and, if so, causes execution of

$$ESV = ESV + L\phi AD(M) \phi FTM(M,I). \quad (15)$$

$$\text{If not,} \quad ESV = ESV + L\phi AD(M) MTG \quad (16)$$

is executed. In either case, the total energy saved ESV is updated by the proper amount to reflect the energy savings during the monitoring period by turning the load 66 off.

Test 227 determines whether the total energy saved (contents of ESV) exceeds the power which must be shed (contents

SHEDRQ). If so, the system has shed sufficient A.C. load, and exit is made from the SHED routine. If not (or if processing from the steps 214-227 is skipped because one of the tests 207, 210 or 212 failed indicating that the M-th load could not be turned off), the SHED algorithm examines (test 230) whether or not the contents of M equal N (the last of the system loads 66.). If not, the variable M is incremented (step 250) (e.g., by $M = M + 1$) and processing begins in the manner above described by reading in the parameters of the next load to see whether that load can be shed. Thus, data processing for the above considered functional loop begins with the first load ($M=1$) and iteratively continues until either enough power has been shed at the initial, lowest priority level ($J=0$) signalled by the test 227 being satisfied - or until the last load 66. has been processed ($M=N$), and there remains an additional shed requirement (contents of SHEDRQ > 0).

Assuming this latter event (test 230 satisfied), the priority level J is incremented ($J = J + 1$) and the new level J tested (test 239) to see whether a danger level (DNG) is attained. If so, an output warning is generated by step 240 by a system output alarm device. Assuming the more usual case where a danger level is not reached (test 239 fails), the load indexing variable M is again initialized to 1 to begin iteration of the SHED algorithm in the manner above discussed to sequentially consider each load in turn, but at the next higher priority level.

Thus, again by way of summary, the SHED algorithm operates by serially examining loads 66, - 66., turning off those which may be turned off and which are of the lowest priority. Assuming that sufficient power cannot be shed at the lowest priority level, the priority variable J is progressively incremented and each of the loads examined seriatim until the requisite power has been deleted.

The composite system of Figures 1 - 3 thus operates in the manner above described to control loads 66 in a manner assuring that excessive power is not consumed during a monitoring period (and thus no utility-imposed penalty or premium is incurred) because of an excess peak power demand, and shedding loads as required. Where loads are shed, such shedding is effected on a priority basis, and in accordance with load defining parameters and priorities defined by load operational levels automatically or manually sensed or entered into the overall power regulating system.

The above-described arrangement is merely illustrative of the principles of the present invention. Numerous modifications and adaptations thereof will be readily apparent to those skilled in the art without

departing from the scope of the present invention. Thus, for example, it will be readily apparent to those skilled in the art that the CPU 31 may utilize (and require) confirmation via the register 71 that a particular load 66. is turned off before decrementing SHEDRQ; or that a load 66 is in fact on (and can thus be turned off) before executing step 214 (Fig. 3). Similarly, it is apparent that the value of the variable TIME can be compared to the variables TIMON(M) to turn loads 66 on at the appropriate times. Further, it will be apparent that the term "power" as used herein extends to D.C. energy - as well as other consumables (e.g., gas or other fluids) with appropriate electronic controllers (e.g., valves) replacing the relays 60., and meters being employed.

WHAT WE CLAIM IS:-

1. A load shedding system for controlling the power supplied to a plurality of loads each selectively connectable to a source of energy, comprising stored program controlled digital computer means including a central processing means and memory means communicating with said central processing means, said memory means including data storage means for each load for storing the characteristics and status associated with the load and to be used in determining whether the load should be shed, a plurality of controllable switch means for selectively connecting and disconnecting the loads to and from the energy source, control circuitry responsive to signals issued by said computer means for controlling said controllable switch means, and means for signalling to said computer means the power being consumed by the loads, said computer means including means for projecting the energy consumption of the loads over a measuring interval, excessive power signalling means for comparing said projected energy consumption with a permissible limit therefore and for signalling when the projected consumption exceeds said permissible limit; and load shedding means responsive to said excessive power signalling means indicating an excessive projected energy consumption for examining said data storage means for selectively operating said controllable switch means via said control circuitry to operatively disconnect selected loads from the energy source.

2. A system as in claim 1 wherein said control circuitry comprises a register having a plurality of stages each having an output representative of a desired operative condition for a different load, and a plurality of relays each responsive to the output of an associated stage of the register for controlling the state of an associated one of said plurality of controllable switch means.

3. A system as in claim 2 wherein said control circuitry comprises a plurality of

multi-position switches each including a first pole serially included between said register and one of said controllable switch means associated therewith.

5 4. A system as in claim 3 further comprising status circuitry for supplying information to said central processing means, said status circuitry including an additional register having a plurality of stages, wherein
10 each of said multi-position switches of said control circuitry includes an additional pole connected to a different stage of said additional register.

5. A system as in claim 4 wherein each
15 said controllable switch means includes a contact connected to a different stage of said additional register.

6. A system as in claim 1 further comprising a power distribution bus, and wherein
20 said power consumption signalling means comprises power meter means coupled to said bus.

7. A system as in claim 6 wherein said
25 power meter includes means for supplying synchronizing information to said central processing means.

8. A system as in claim 6 further comprising meter interface circuitry connecting
30 said power meter means and said central processing means, said meter interface circuitry including counter means for accumulating impulses each representative of a fixed quantity of energy consumption.

9. A system as in claim 1 for controlling
35 a first plurality of loads and a second plurality of loads, comprising an additional plurality of controllable switch means each controlling a different one of said second plurality of loads, a remote system controller,
40 additional control circuitry responsive to signals supplied thereto by said remote system controller for controlling the operative states of said additional controllable switch means, and coupling means interconnecting
45 said stored program digital computer means for said remote system controller.

10. A system as in claim 9 wherein said
50 coupling means includes an asynchronous receiver and transmitter means serially connected between said digital computer and said remote system controller.

11. A system as in claim 9 wherein said
remote system controller includes decoder and sequencer means.

12. A system as in claim 10 wherein said
55 remote system controller includes decoder and sequencer means.

13. A system as in claim 1 for controlling
60 a first plurality of loads and at least one additional load, comprising encoder means communicating with said central processing means, a source of power, means for multiplexing power supplied by said power source and control signals generated by said
65 encoder, and remote terminal means comprising

means selectively responsive to said multiplexed power and encoder supplied signals supplied by said multiplexing means for energizing said at least one additional load with the power supplied thereto.

14. A system as in claim 13 wherein said
remote terminal means includes a separation filter for separating said control signals from said multiplexed signals, a decoder responsive to said separated control signals,
7 and latch and relay means responsive to said decoder for supplying said power to said additional load.

15. A system as in claim 1 wherein said
stored program controlled digital computer
8 includes priority interrupt means for altering a priority associated with a load to be used in determining whether the load is to be shed, said priority interrupt means being
8 responsive to means for detecting a failure of said energy source and to a manual input device.

16. A system as in claim 1 wherein said
energy consumption projecting means includes means for determining the present
9 rate of energy consumption responsive to the signals provided by said consumption signalling means, means for determining the power consumed since the beginning of the measuring interval, means for computing
9 the potential energy consumption over the remainder of the measuring interval by determining the product of the time remaining to the end of the measuring interval and the present rate of power consumption, and
1 means for summing the energy actually consumed up to the present with the potential energy consumption during the remainder of the measuring interval.

17. A system as in claim 16 wherein said
1 means for determining the present rate of consumption includes means for effecting a weighted average of signals indicative of power consumption during a most recent
1 sampling interval and power consumptions measured during earlier intervals.

18. A system as in claim 16 including
means for determining the energy saved by turning a load off by effectively multiplying
1 the rate of power consumption with either the period the load is to be shut off or the remainder of the measuring interval, depending on which is the lesser.

19. A system as in claim 1 wherein said
data storage means for each load includes
1: means for storing the relative priority of the associated load, and wherein said load shedding means comprises means for iteratively
1: examining said data storage for the loads on a monotonically increasing priority basis, said central processing means shedding
loads via said control circuitry and said controllable switch means on a monotonically increasing priority basis.

20. A system as in claim 19 wherein said

data storage means for said loads stores characteristics which vary depending upon a load operational level variable, means being provided for prescribing a value for said load operational level variable.

21. A system as in claim 20 wherein said data storage means for the loads stores operational level dependent minimum on and off time variables related to the minimum times the loads should be connected to and disconnected from the energy source, and priority variables related to the relative priorities of the loads, and operational level independent status variables related to the status of the loads, power variables related to the power consumptions of the loads, and transaction time variables related to the times the loads were last actuated or deactuated.

22. A system as in claim 1 wherein said load shedding means includes testing means for determining whether a load described by data in said storage means may be turned off, said testing means including means for testing a priority and status associated with the load.

23. A system as in claim 22 wherein said excessive power signalling means computes the amount of energy which must be shed responsive to detecting excessive power consumption and wherein said load shedding means comprises means for computing the energy saved over a measuring interval for each load shed, and means for decrementing a stored variable with the energy

saved when a load has been turned off.

24. A system as in claim 1 wherein said data storage means for each load stores parameters dependent upon an operational level, and wherein said load shedding means includes iteratively operative means arranged to examine data stored for each load and compare priorities associated with the loads with a predetermined priority level, and then repeat the operation for successively increasing values of said predetermined priority level.

25. A system as in claim 1 wherein said data storage means for each load includes means for storing a plurality of values for at least one load characteristic, each value being operative for a distinct operational level, and said memory means includes means defining the then obtaining operational level.

26. A system as in claim 25 wherein said central processing means and memory means include indirect addressing means for processing load characteristics dependent upon said level defining means.

27. A load shedding system substantially as herein described with reference to the accompanying drawings.

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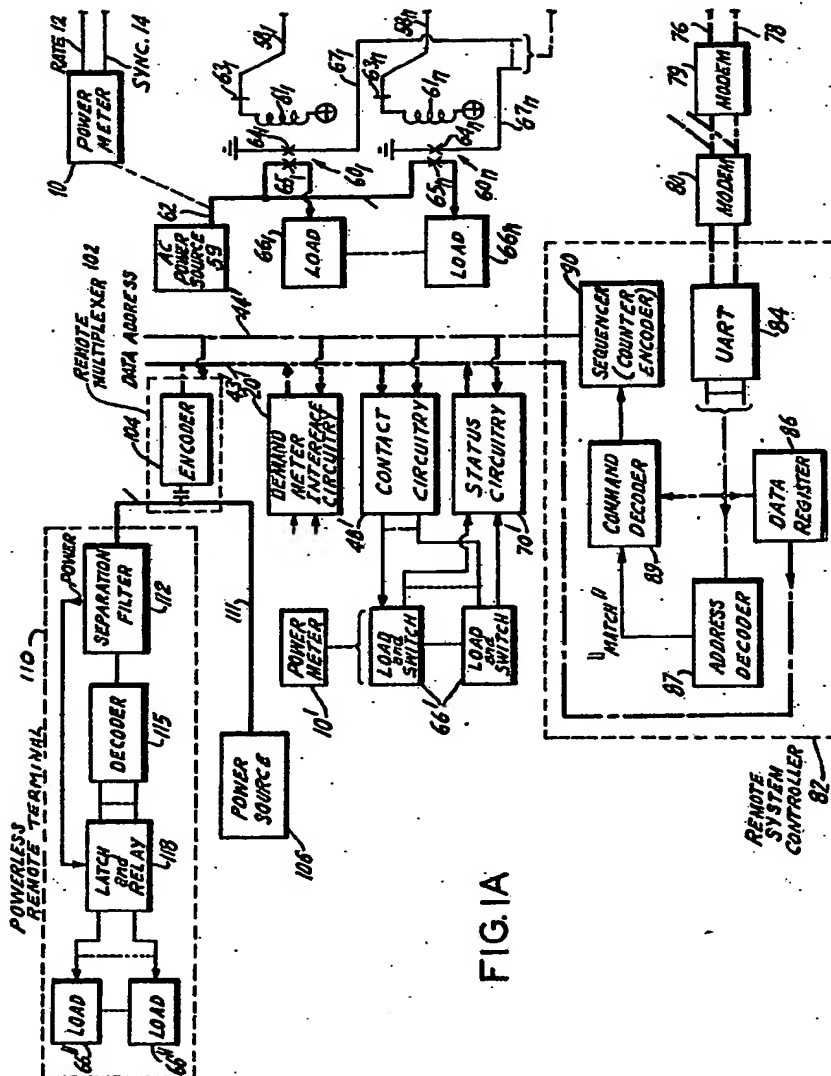


FIG. 1A

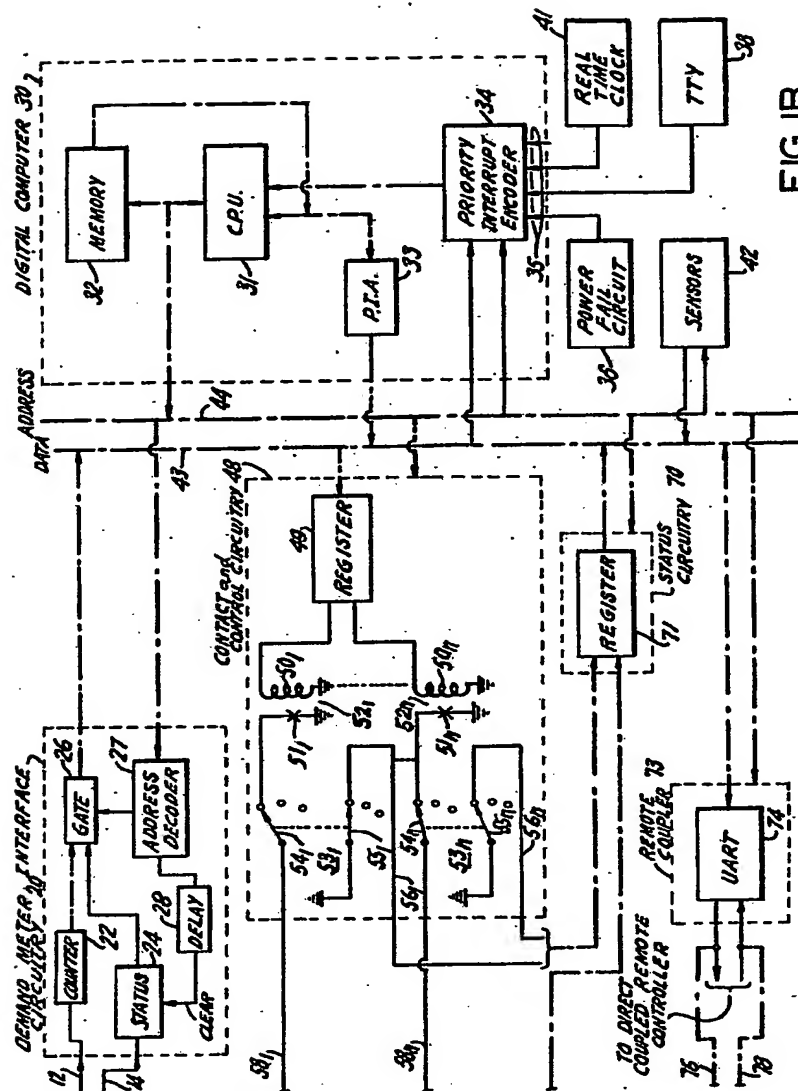


FIG. 1B

FIG. 2

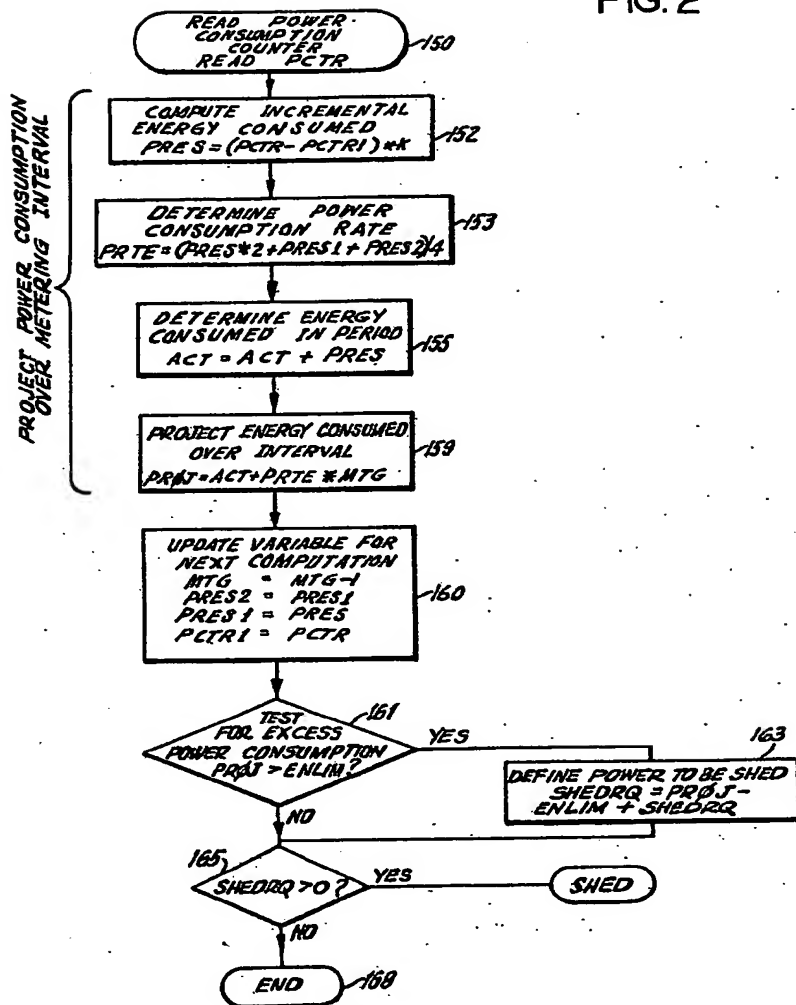
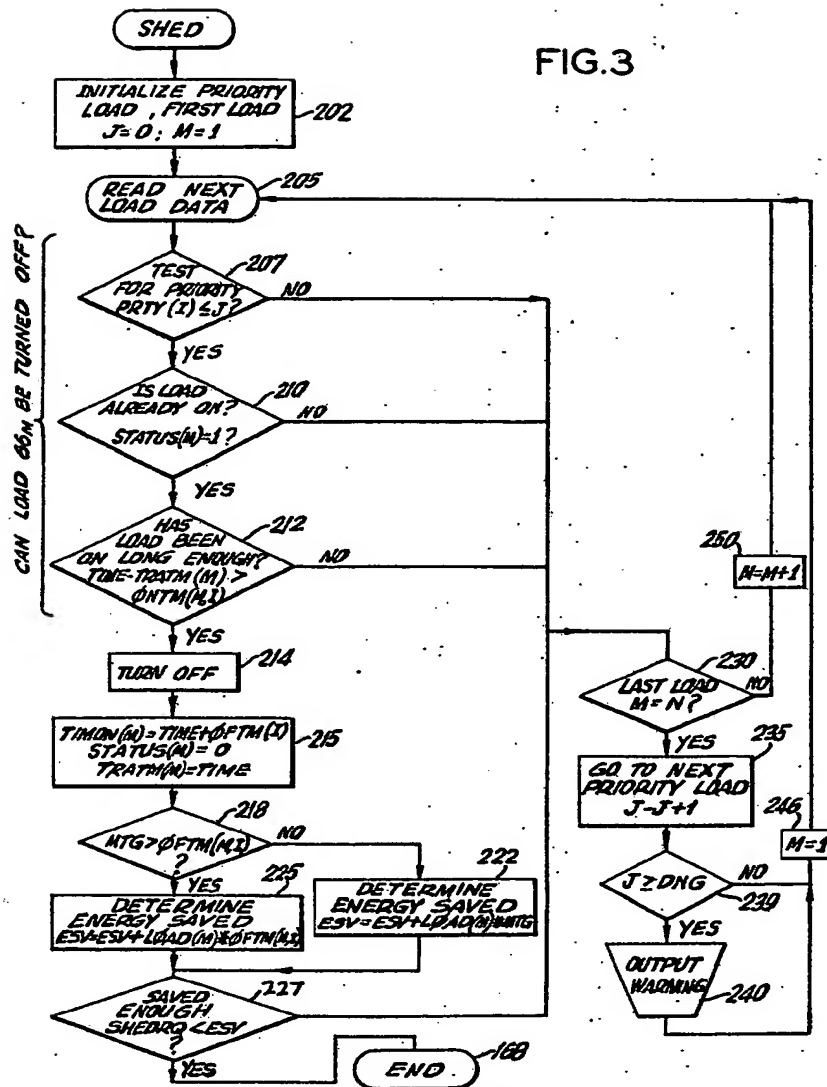


FIG.3



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